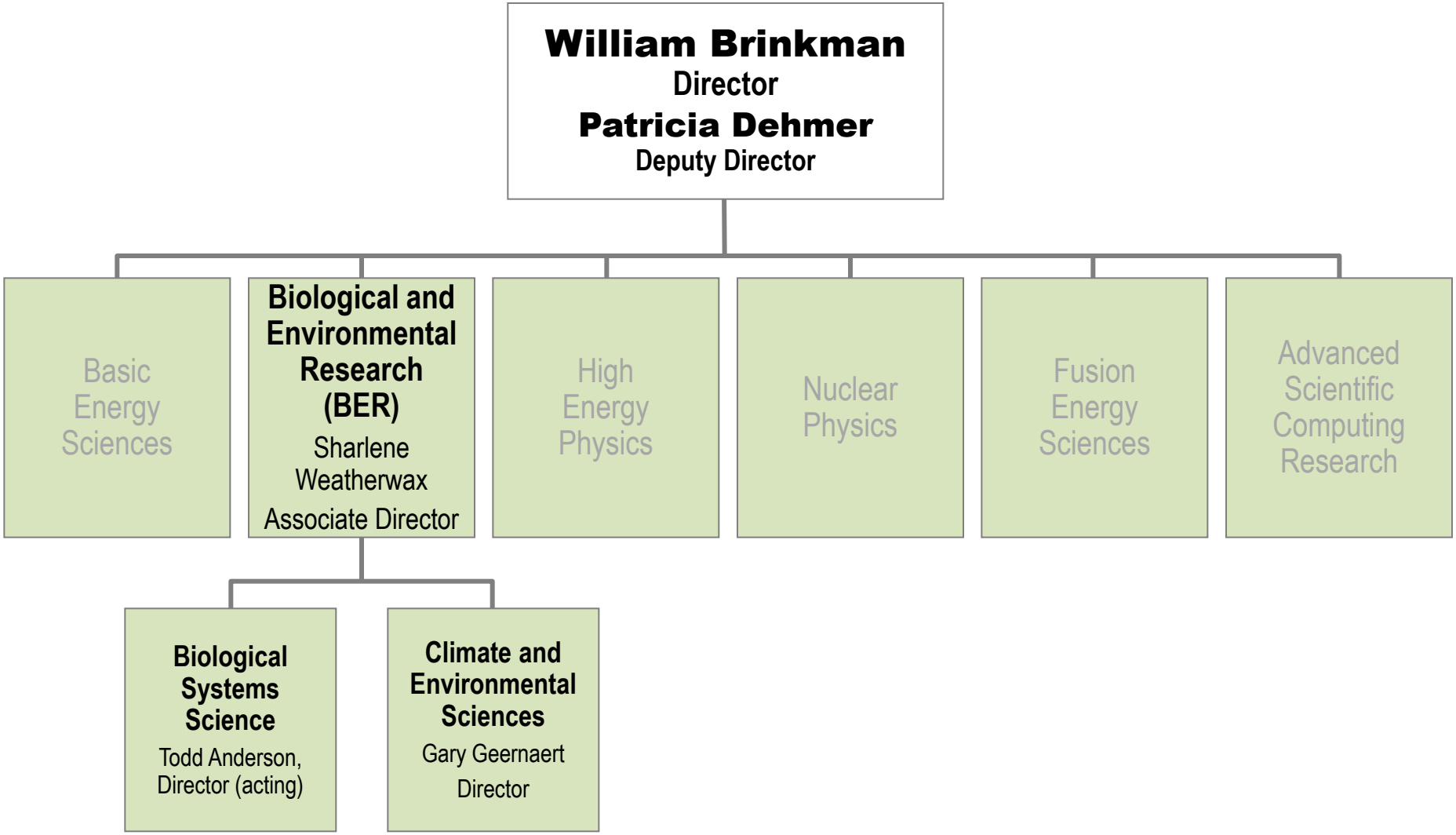
Arctic science research at the U.S. Department of Energy

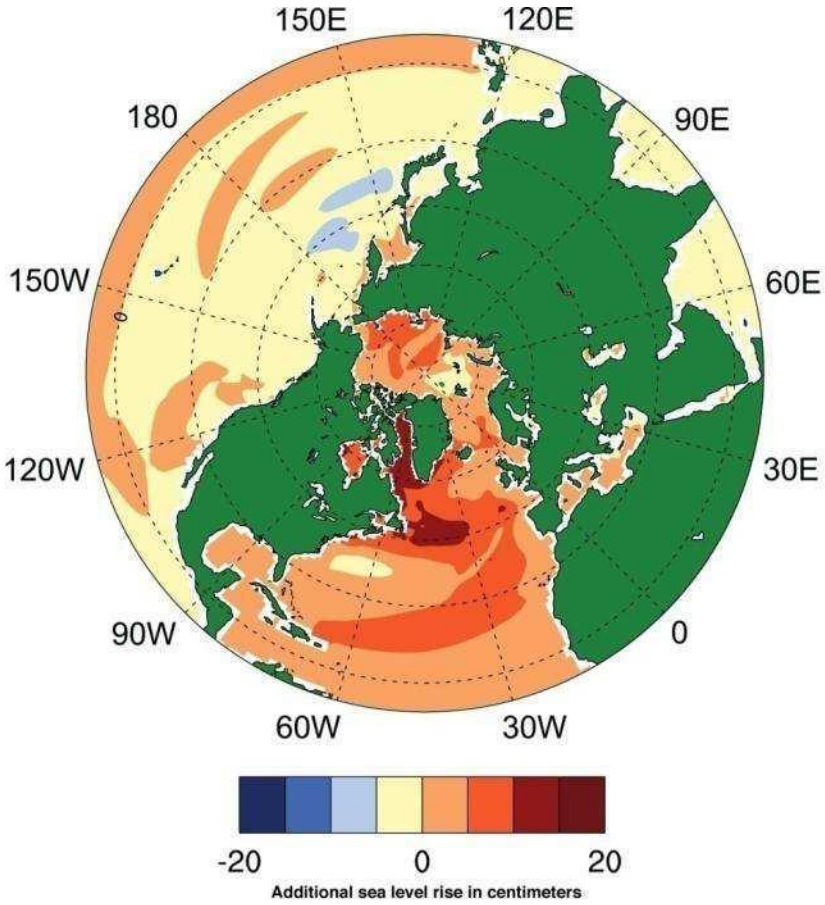
Gary Geernaert, Ph.D.
Climate and Environmental Sciences Division
U.S. Department of Energy

Department of Energy Office of Science



GOAL: Climate Change Research
The climate-energy nexus

"Advance climate change research to provide knowledge of effects of greenhouse gas emissions on Earth's climate and biosphere—supporting effective energy and environmental decision making"



Modeling the impacts of climate change
Sea-level rise modeled with the Community Climate System Model

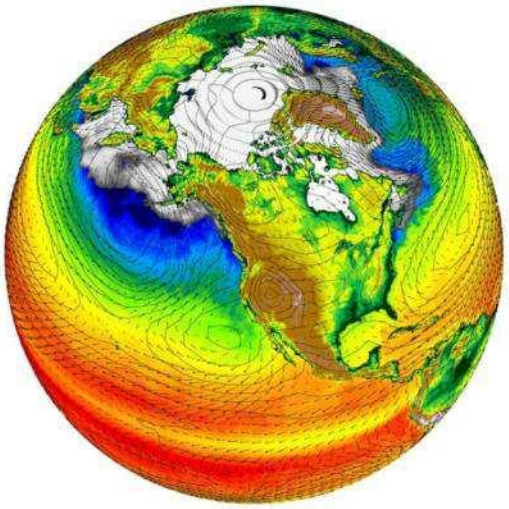
Portfolios

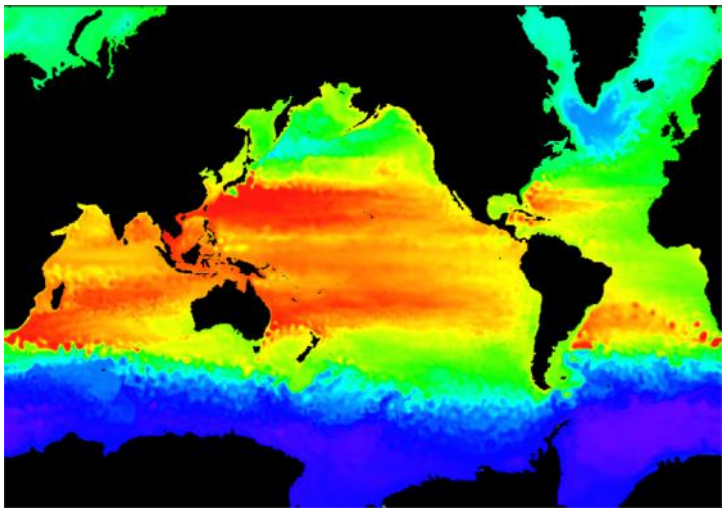
- Modeling and Prediction
  - Regional models
  - Regional Arctic System Model (RASM)
  - Community Earth System Model (CESM)
  - Integrated assessments
- Ecosystem research
  - Ameriflux, FACE, SPRUCE
  - NGEE Arctic
  - Amazon
- Atmospheric System Science
  - Atmospheric Radiation Monitoring facilities

Climate and Earth System Modeling

Regional, Global, and Earth System Modeling

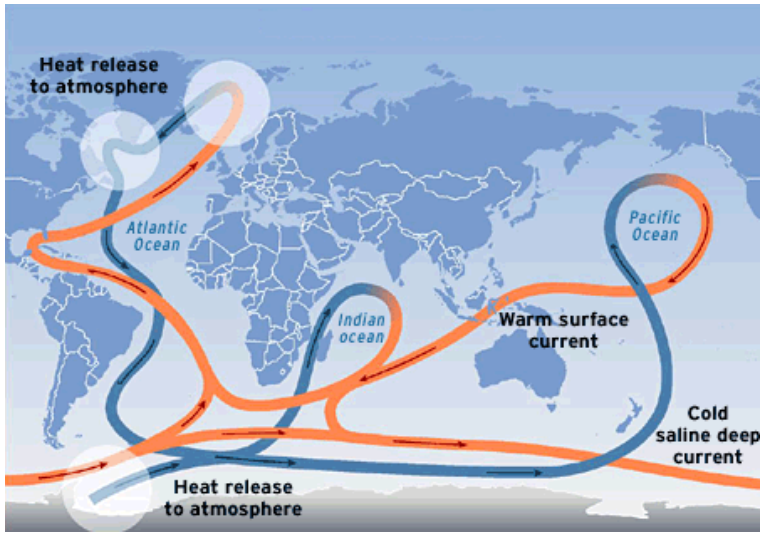
- Develop and test models based on definitive theoretical foundations
- Develop better representations of key climate processes
- Develop diagnostic methods and tools to evaluate models
- Increase fidelity and throughput of climate change projections
- Examine issues related to climate change detection and attribution
- Dynamic grids, high resolution
- Modes of variability, extreme events

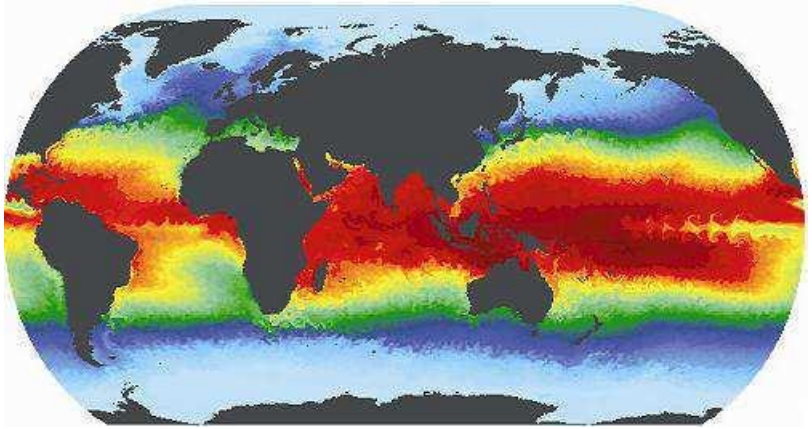




Ocean Questions

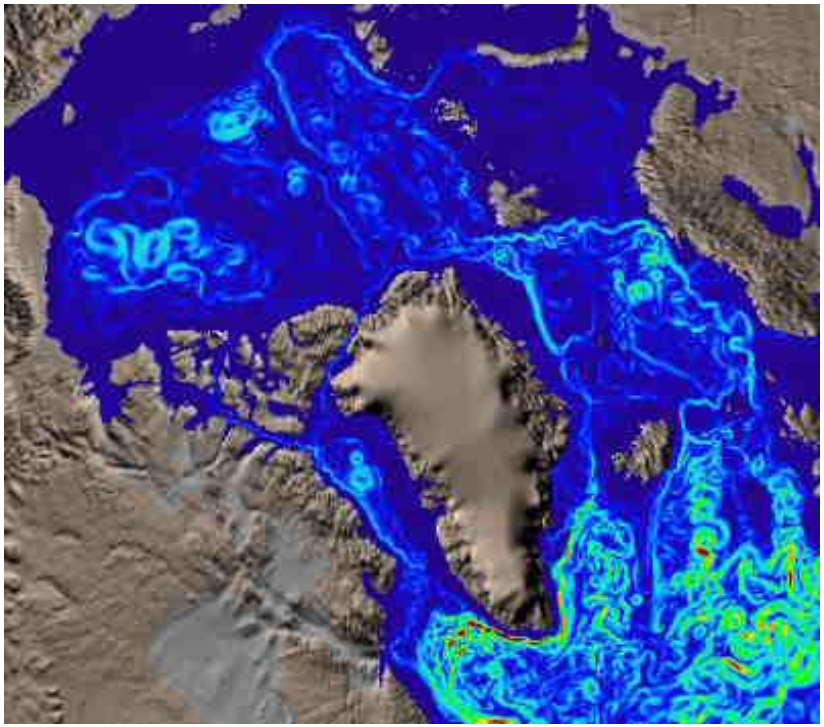
- Thermohaline variability
  - Stability of circulation
  - Role in decadal climate variability (eg AMO)
  - Heat transport
- Decadal variability
  - PDO, AMO
  - Ocean has long time scales
- Ocean acidification
- Ocean heat and carbon uptake
- Role of mesoscale eddies in circulation and climate
- Oceans and hurricanes





Ocean Model Development

- Parallel Ocean Program (POP)
  - Ocean general circulation model developed at LANL
  - Ocean component of the DOE-NSF Community Earth System Model (CESM)
  - Advanced algorithms and physical parameterizations
- Eddy-resolving ocean simulations
  - High resolution ocean simulations to resolve mesoscale eddies with sizes of 20-50 km
  - Arctic circulation highly sensitive to a variety of ocean processes

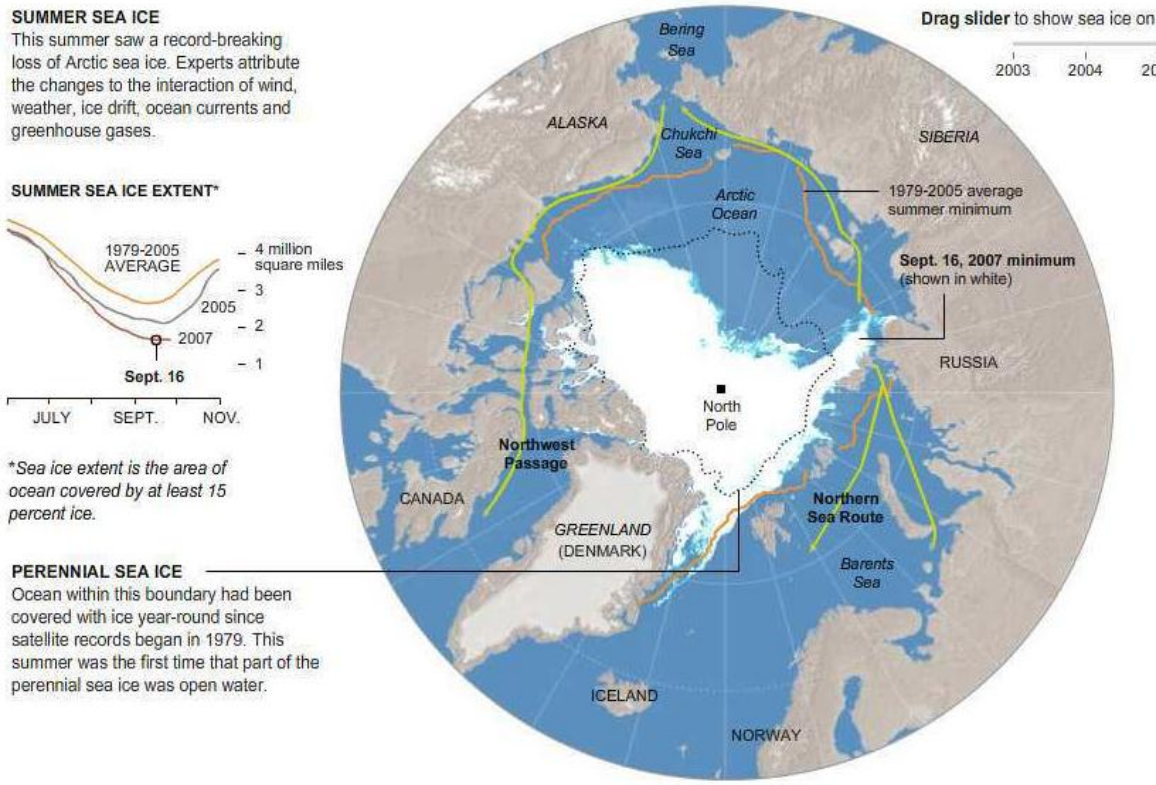


Arctic current speed from a global eddy-resolving simulation using POP

Sea Ice Questions

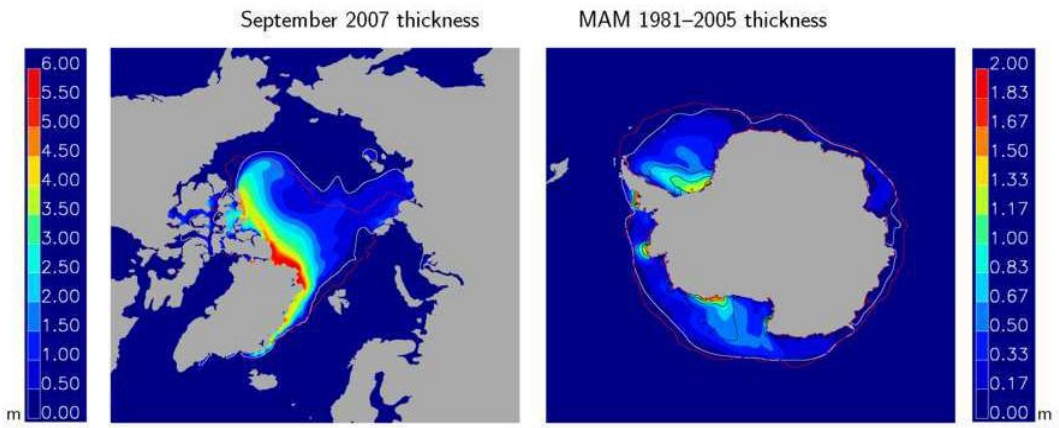
NY Times, 10/1/07

- Abrupt changes and high variability in Arctic ice
  - Causes
  - Impacts
- Large ice feedbacks on climate system
- Ice free summer soon
- Similar roles in Antarctic



National Oceanic and Atmospheric Administration; a- Champaign; Donald K. Perovich, U.S. Army Cold

Erin Aigner, Jonathan Corum, Vu Ng



Atmosphere: Science Questions

- An overarching goal of the RASM project is to simulate features that are smaller than can be resolved with current global climate models but are climatically important

- Atmospheric examples:
  - Cyclone intensity / polar lows
  - Mesoscale features such as topographically forced winds (Greenland tip jets)
  - Details of atmospheric forcing for melt over the Greenland ice sheet

Regional Arctic System Model (RASM)

- Modeling weaknesses to overcome
  - large errors in arctic component climate model simulations
  - air-sea-ice feedbacks generally missing
- Observed rapid changes in Arctic climate system
  - Sea ice
  - Permafrost
  - Greenland ice sheet
  - Temperature
- History: started in 2007
  - Wieslaw Maslowski: Naval Postgraduate School
  - John Cassana: University of Colorado
  - William Gutowski: Iowa State University
  - Dennis Lettenmeier University of Washington
- Investments updated based on “Science Plan for Arctic System Modeling” – Roberts et al., 2010

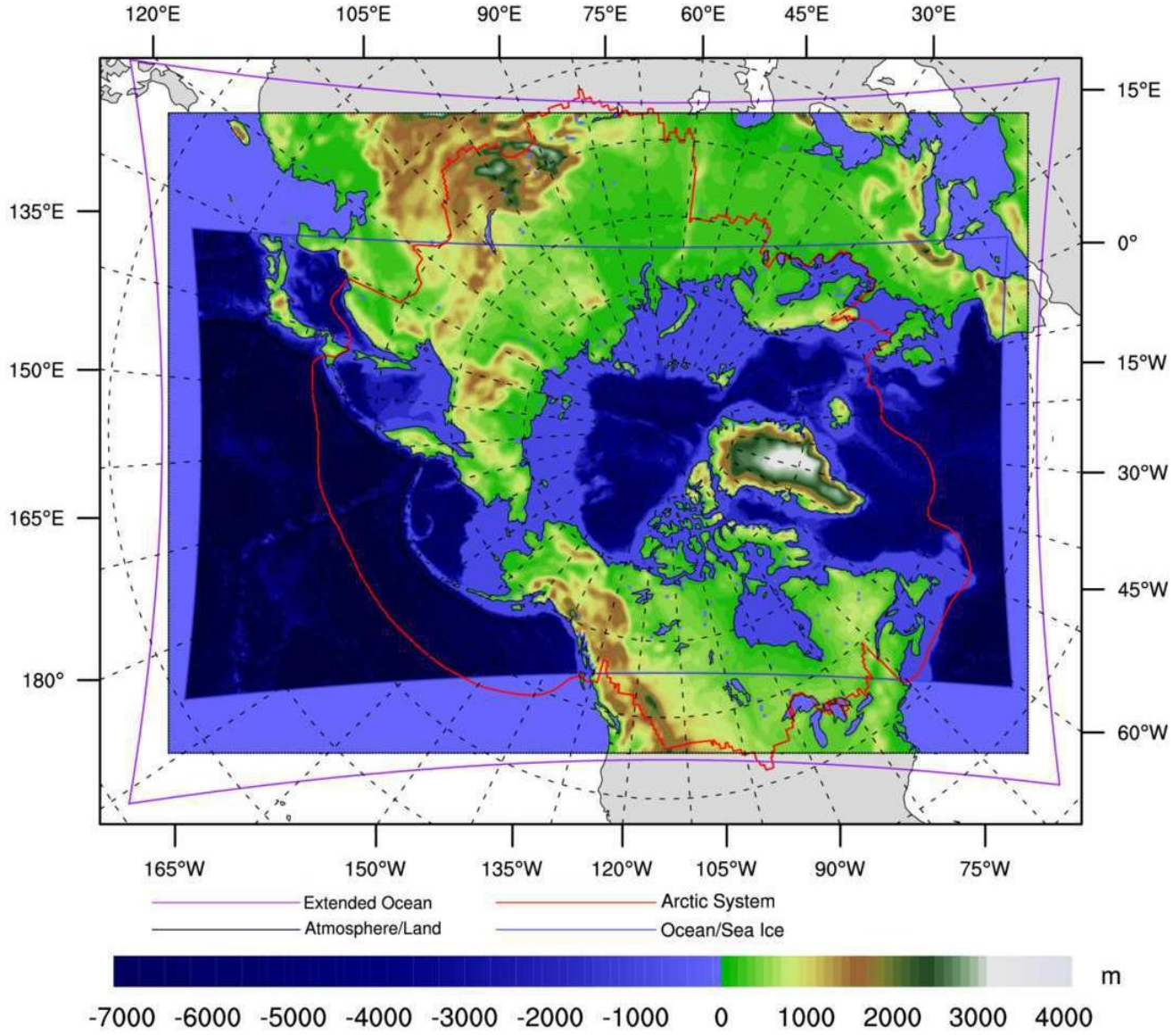
Regional Arctic System Model (RASM)

Renewal: (2011-2015) DOE / RGCM project
PI's: Same + Lipscomb, Tulaczyk Zeng, Robertson

- **Atmosphere - Polar WRF** (gridcell ≤50km)
- **Land Hydrology – VIC** (same as WRF)
- **Ocean - LANL/POP** (gridcell ≤10km) |-> RACM
- **Sea Ice - LANL/CICE** (same as POP)
- **Flux Coupler – NCAR CPL7**

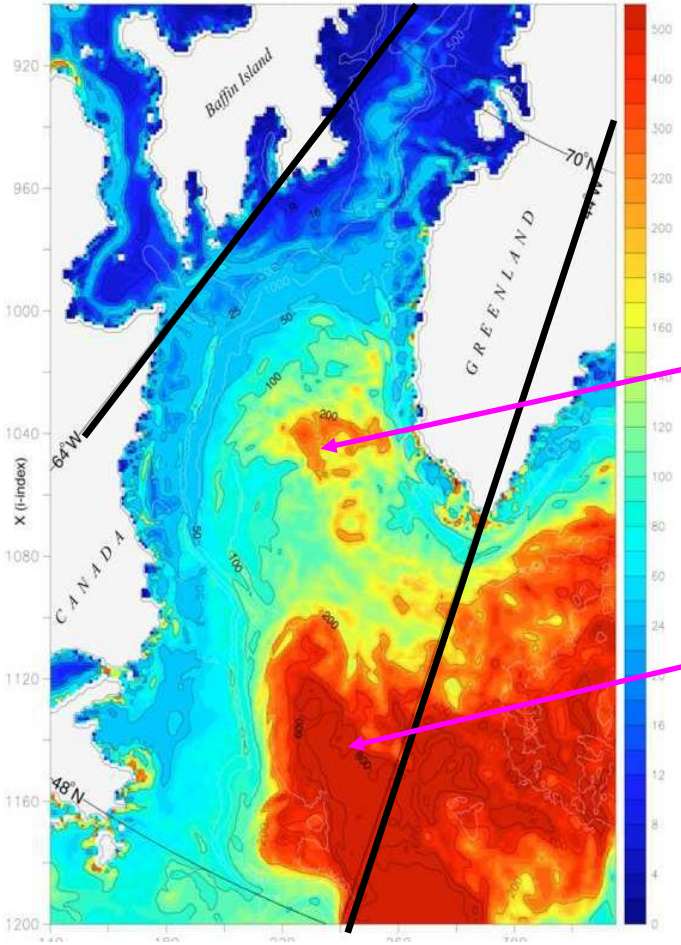
- **Dynamic Vegetation – VIC(4.1.1) + CLM(4.0)** (same as WRF)
- **Dynamic Ice Sheet – Glimmer-CISM plus** (gridcell ≤5km)
  - Basal sliding due to meltwater penetration to the bed
  - Ocean thermal forcing of ice sheets and tidewater glaciers
- **Glacier and Ice Caps (GIC)**
  - A new parameterization for evolving area and volume of GIC in VIC

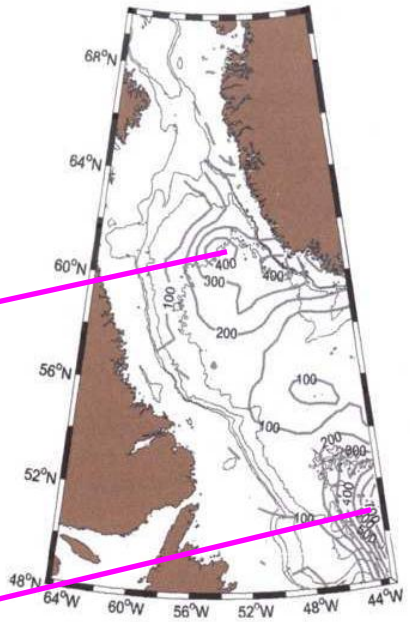
RACM / RASM Domains for Coupling and Topography



Pan-Arctic region to include:
-sea ice covered ocean in the northern hemisphere
- Arctic river drainage
- critical inter-ocean exchange and transport
- large-scale atmospheric weather patterns (AO, NAO, PDO)

RASM Ocean Model – LANL/POP

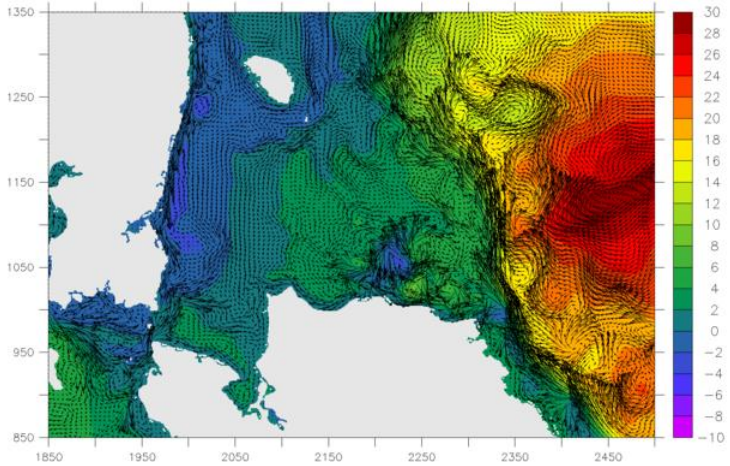




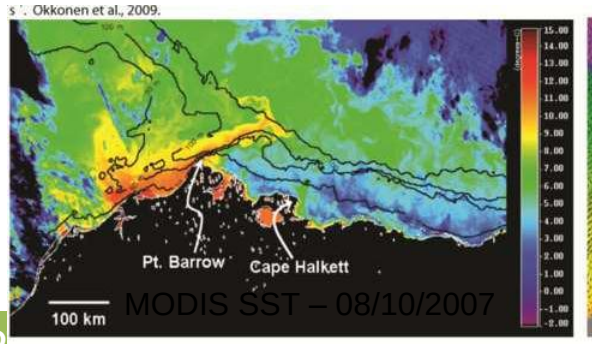
Map of eddy kinetic energy deduced from surface drifter data. Values are in cm^2/s^2. Drifters released in the North Atlantic and Labrador Sea during the 1990s. Courtesy J. Cuny, University of Washington.

1/12º (~9-km) Modeled Eddy Kinetic Energy close to observed in sub-polar seas such as Labrador

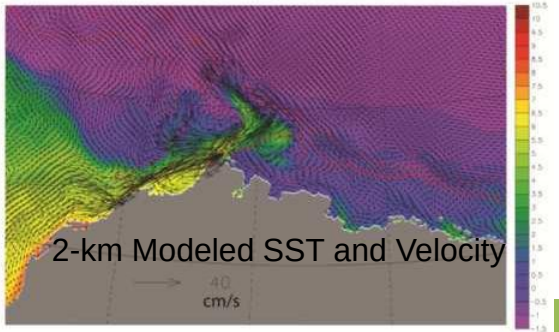
POP configuration at 1/48º (~2.3km) or higher required in the central Arctic Ocean to resolve eddies, coastal currents and transport through Bering Strait



Eddy resolving Arctic Ocean models can capture details of ocean circulation, eddy generation and heat distribution



MODIS SST – 08/10/2007

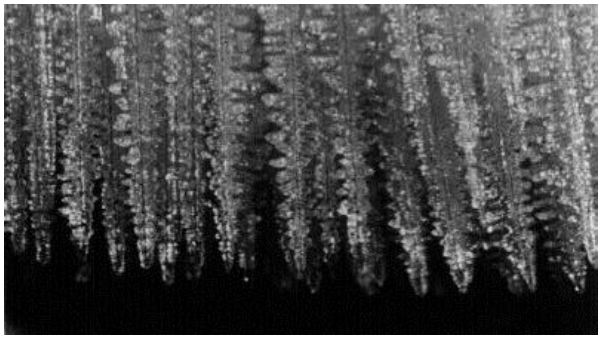


2-km Modeled SST and Velocity

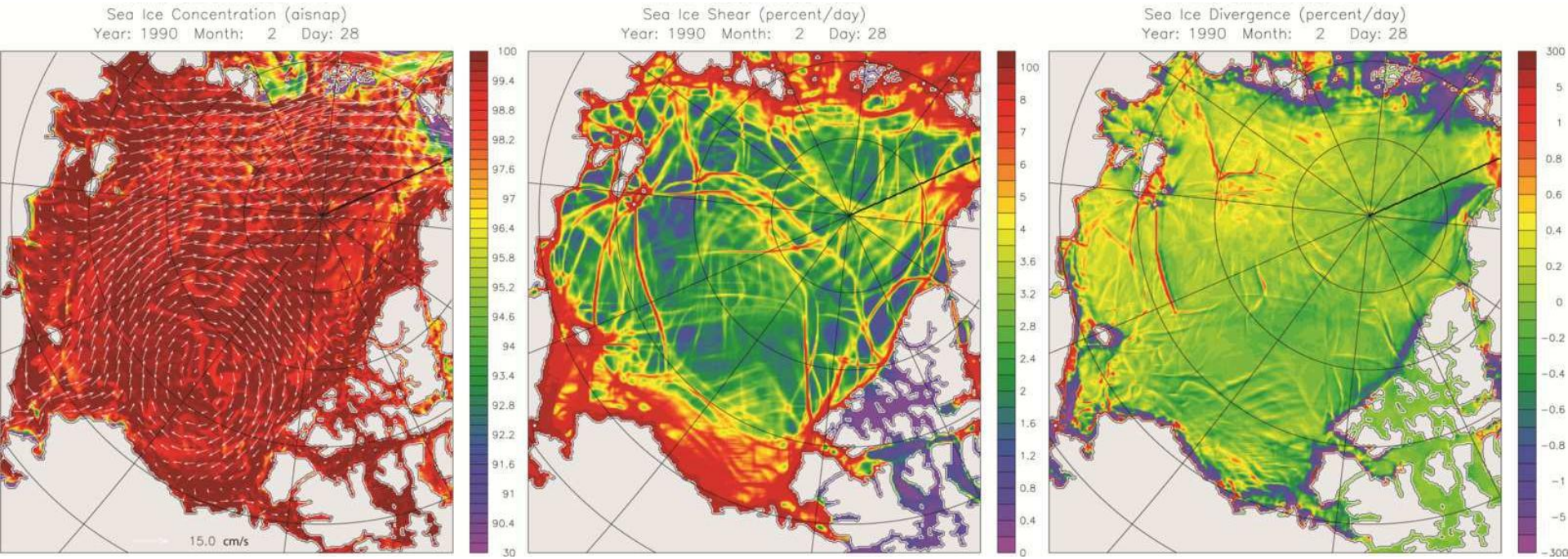
Sea Ice Model development

- Multi-phase ice model
  - Transport of water/brine through ice, brine channels
  - Mushy layer at ice base
  - Snow on ice, melt ponds
  - Ice age tracer
  - Ice bergs
- Ice-ocean boundary
  - Ice pressure
  - Momentum transfer
- Biogeochemistry
  - Ice algae
  - Albedo, multi-phase feedbacks
  - Carbon deposition on ice

Los Alamos Sea Ice Model (CICE)



Arctic Sea Ice Model – LANL/CICE



Sea ice drift is affected by Ice thickness and affects deformations

Sea ice shear and divergence affect:
- air-sea exchange, especially in winter (feedback on atmosphere)
- thickness distribution

Both sea ice drift and deformations require realistic high-resolution atmospheric forcing

1/12º RASM / CICE Summary:
- energy-conserving thermodynamics with: 5 categories, 4 layers per category, multi-snow layer, melt ponds, nonlinear T, S profiles
- EVP dynamics
- energy-based multi-category ridging and ice-strength
- 2-D remapping scheme for horizontal ice transport
- 1-D remapping scheme for updating the thickness distribution

Melt Ponds on Sea Ice

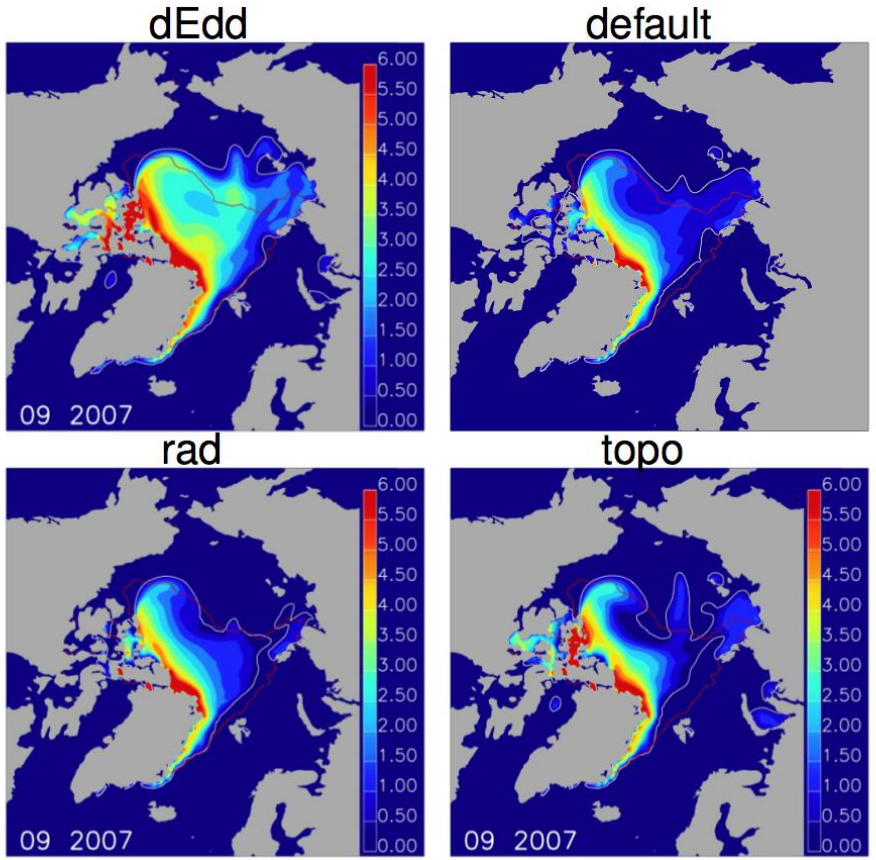
Work in progress

Objective

- Improve sea ice radiative properties (albedo) by calculating effects of melt ponds

Approach

- Compare existing melt pond parameterizations within the CICE model code:
- 1) default parameterization
- 2) 'rad' CCSM4 radiative-only ponds
- 3) 'topo' UCL explicit ponds
- 4) delta-Eddington radiation scheme with no ponds

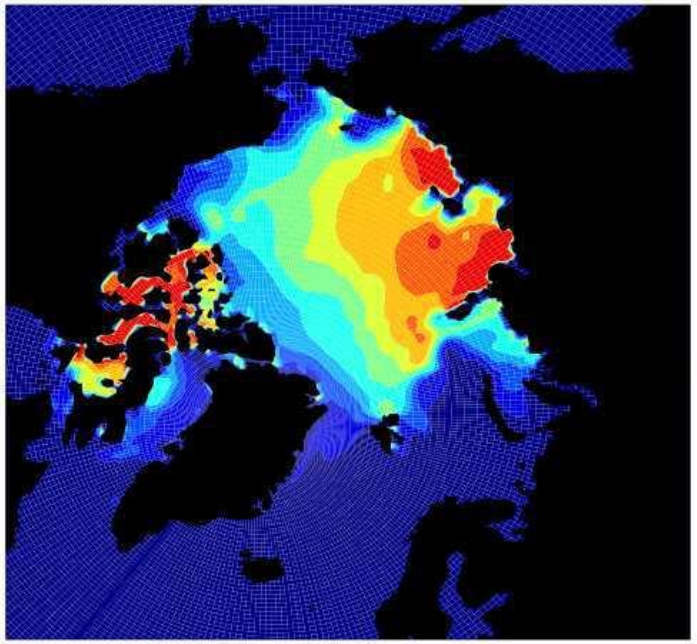


Sea ice thickness (m) in September 2007 in 4 simulations. The red contour is the 15% concentration from passive microwave satellite observations; the white contour is the model's 15% concentration.

Holland, et al. "Improved sea ice shortwave and radiation physics in CCSM4: The impact of melt ponds and black carbon," *J. Clim.* In review.
Flocco et al., 2010. "Incorporation of a physically based melt pond scheme into the sea ice component of a climate model." J. Geophys. Res. **115**.

Arctic ocean and ice biogeochemistry

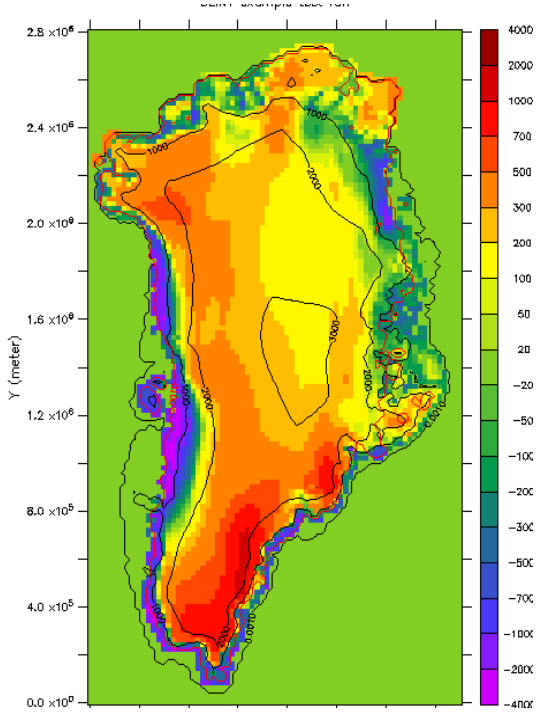
- Ecosystem and biogeochemical processes added to Los Alamos ocean and ice models
  - Carbon and sulfur cycles for both greenhouse gases and aerosols
  - Ecosystem models plus trace gases like dimethyl sulfide
- High latitude ecosystems
  - Ice algae, related food webs
- Methane clathrate/hydrates
  - Simulate the fate of ocean sea floor methane hydrates under climate change scenarios
  - Los Alamos, Lawrence Berkeley, Lawrence Livermore collaboration
- Ocean pH changes



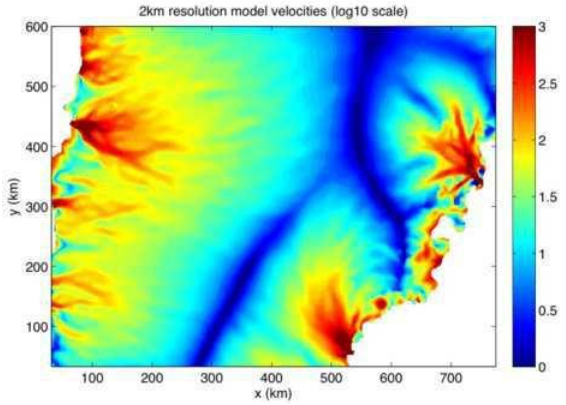
Preliminary simulation of ice algae concentrations

LANL Land ice in RASM

- Northern latitudes only
- Two modeling components
  - Glimmer Community Ice Sheet Model
  - New surface-mass-balance scheme
- Coupled to regional atmospheric model
- Topographic effects (high resolution



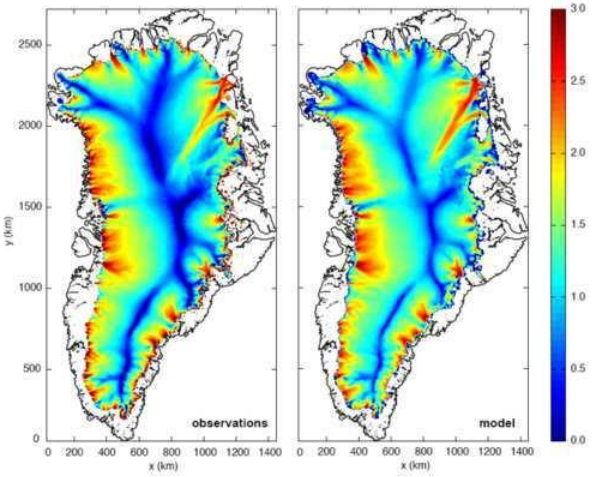
Greenland SMB from CESM



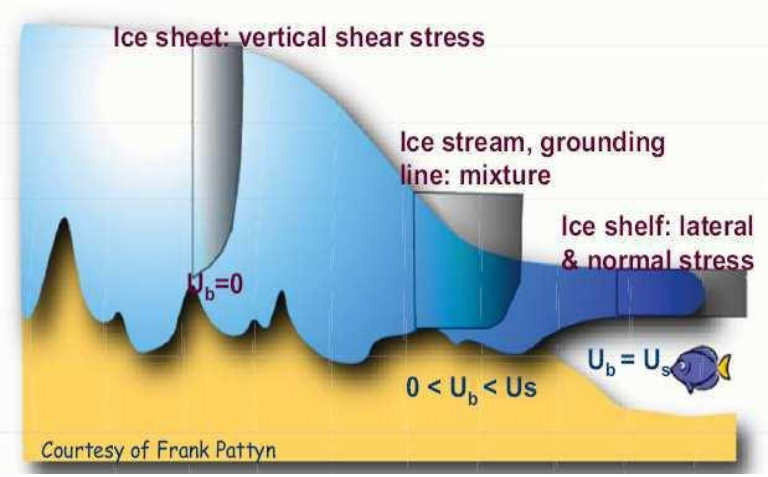
Greenland surface ice speed from Glimmer-CISM

Dynamical Ice Sheet Modeling

- Community Ice Sheet Model at LANL
  - Full dynamical ice sheet model for Greenland and W. Antarctic
  - Ice sheet component of the DOE-NSF Community Earth System Model
- New developments
  - Basal sliding
  - Hydrology
  - Ice shelf/ocean interactions and ice shelf buttressing
- Ocean model development
  - Ice shelf/ocean interactions and flow under shelf
  - Thermal expansion of ocean
  - Variable coastlines, coastal inundation



Model ice sheet velocity compared to observed



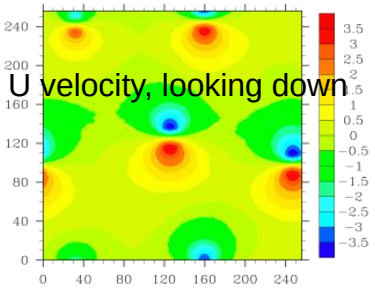
Deep Arctic Ocean Dynamics

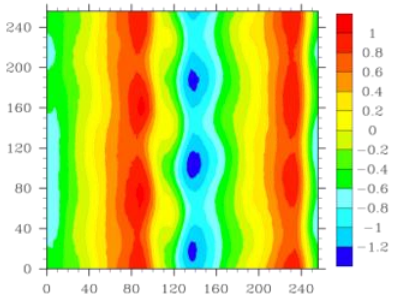
Numerical Simulations

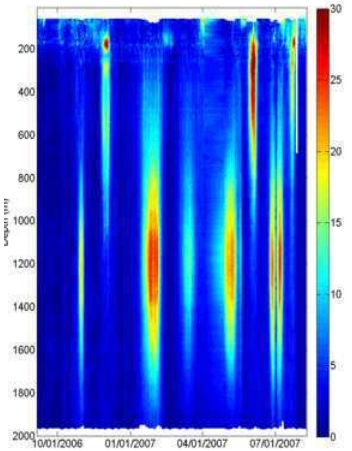
Objective: Combine slow dynamics with nonhydrostatic dynamics

Research:

- rotational and nonhydrostatics
- ***Projection Operator*** that switches from hydrostatic to nonhydrostatic depending on the stratification and vorticity.







Observations of columnar vortices with large KE --Beaufort Gyre Exploration Program, National Science Foundation

Reference:Wingate, B. Embid, P., Holmes-Cerfon, M. Taylor, M. "Low Rossby Limiting Dynamics for Stably Stratified Flow with Finite Froude Number, Accepted to Journal of Fluid Mechanics, 2011 (ALSO Supported by the ASCR Multiscale Math program)

Atmospheric Research – Facility/Research

- Objective: how radiation balance is affected by clouds, aerosols, and greenhouse gases
- Two components
  - ARM Climate Research Facility (ACRF)
  - Atmospheric System Research

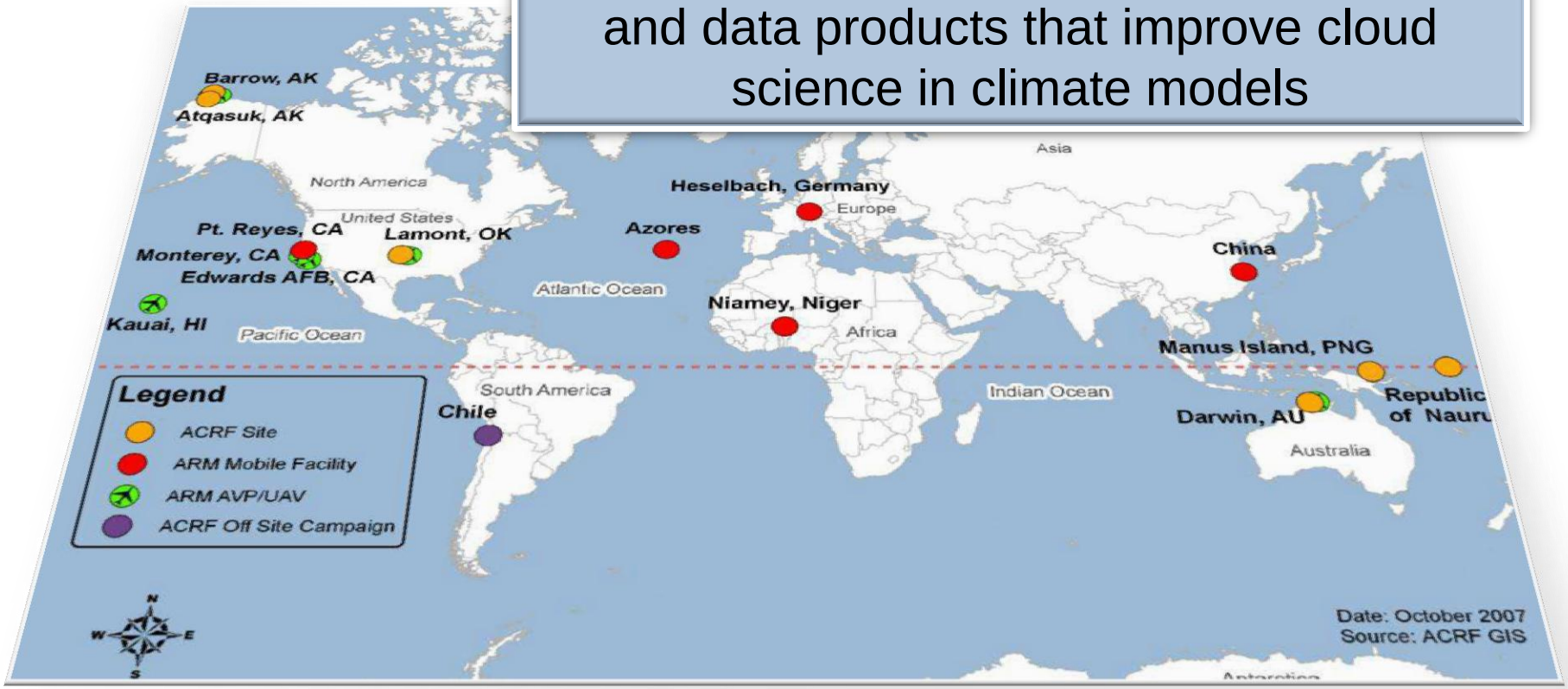
Radar Wind Profiler and radio acoustic sounding system (RASS), Barrow, Alaska

DOE Scientific User Facility

ARM Climate Research Facility

2 mobile & 3 fixed sites

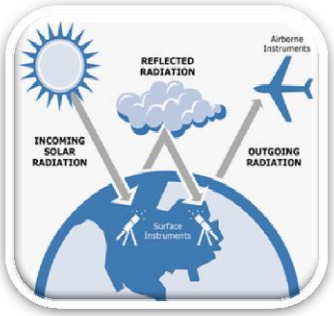
Provides continuous field measurements and data products that improve cloud science in climate models

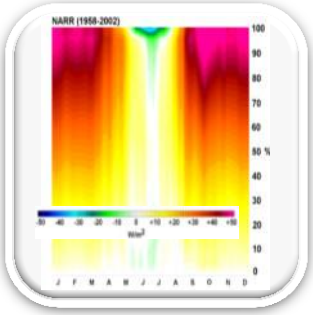


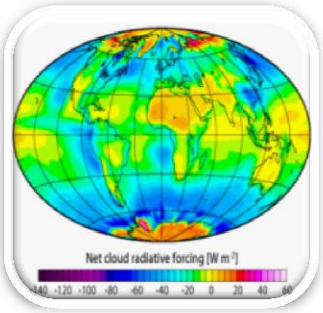
Atmospheric System Research

- Use of ACRF short- and long-term climate measurements
- Analysis, theory, process modeling, and retrospective climate simulations and evaluations
- Enhanced cloud and radiation formulations used to improve decadal climate predictions
- Aerosol radiative forcing of climate, including laboratory and field experiments, modeling, and instrumentation

ACRF measurements → Analysis and theory → Process modeling and evaluation







Multiagency MILAGRO campaign (Megacity Initiative: Local and Global Research Observations) Mexico City, 2006

Next-generation ecosystem experiment: Arctic tundra

- Targets a system that is globally important, **climatically sensitive**, understudied, feasible--tundra with underlying permafrost
- Warming could cause a **large** net release of CO_2 and/or CH_4 to the atmosphere — a strong positive feedback to warming
- Warming might also reduce albedo (surface reflectivity)
- BER bring unique scientific expertise in:
  - Large scale ecological experiments
  - Ecogenomics and microbial ecology
  - Atmospheric exchange
  - Radiative forcing

Thank you!

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